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DYNAMIC VISUAL ACUITY MEASUREMENT

THE DESIGN AND CONSTRUCTION OF A CLINICALLY USEFUL INSTRUMENT

KIM HOOVER

JOHN INVERSO

THESIS

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR A DOCTORATE OF OPTOMETRY

ADVISOR APPROVAL

HAROLD M. HAYNES, O. D.

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ABSTRACT

A dynamic visual acuity (DVA) measurement apparatus was designed, constructed, and tested for reliability. The apparatus was designed so that it was compact in size, light in weight, of reasonable cost, and adaptable to common projection systems. Directions, drawings, and diagrams were included so that a practicing optometrist with considerable understanding of optics and limited knowledge of simplified electronics could easily assemble the apparatus. The realiability testing results showed that this DVA measurement apparatus can be useful for both testing and training DVA. It was easy to use and provided a complete DVA profile within a few minutes.

PURPOSE

Since much of human interaction with the environment involves observation of moving targets, it seems imperative that dynamic visual acuity skills be considered when a patient presents himself for a vision analysis. Consequently, the purpose of this project was the design, construction and testing of the reliability of an apparatus to measure dynamic visual acuity which could be constructed and used by practicing optometrists.

The criteria for the design and construction of this apparatus were that 1) the component parts should be readily available from hobby shops and electronic parts stores; 2) the directions should include sufficient drawings and diagrams such that a person with considerable understanding of optics and limited knowledge of simplified electronics could acquire and assemble this apparatus; and, 3) the instrument should be of compact size, light in weight, adaptable to the common projection systems in use and of a reasonable cost.

LITERATURE REVIEW

Since an individual's interaction with his environment is dynamic in nature, it has been considered that many visual tests are inappropriate because they measure static performance.[1] Dynamic Visual Acuity (DVA) is the measurement of the minimum angular levels of visual discrimination (visual acuity tests) for targets moving at specified angular velocities relative to the nodal point of the eye to a given discriminatory criteria.

In general, research has demonstrated some correlation between Static Visual Acuity (SVA) and DVA at low angular velocities, a correlation which decreases or disappears as the angular velocity is increased.[2,3,4,5,6,7] Individuals with the same SVA often differ markedly on DVA performances.[7] The ability of drivers to correctly read road signs has a demonstrated positive correlation with DVA, but not with SVA.[5] Of the vision variables, DVA was the most consistent predictor of automobile accidents to the front and sides,[8] although DVA alone remains a poor predictor because of more important nonvisual variables such as age and average annual mileage.[9]

When presented with a moving target, the subject typically makes two or more saccades, each followed by a smooth pursuit. Humans are capable of exerting smooth pursuits up to 90^{o}/second, but only after at least two saccades when target velocities are between 50^{o} and 90^{o}/second.[10] As the target velocity is increased, the frequency of third saccades increases, the saccadic latencies decrease and the pursuit inaccuracies increase.[11] These eye movement characteristics result in position errors, which place the target image at an extrafoveal position, and in velocity errors, which create movement of the image on the retina.[11]

It has universally been found that as the target velocity increases, the measured VA decreases.[2,3,4,11,12] The range between individuals of threshold acuities also increases as the velocity increases.[12]

Increasing the illumination or target constrast improves the DVA.[2,13] While increasing the luminance above 10fc has a negligible effect upon SVA, DVA shows improvement at least to the 500fc level.[14] Subjects' saccadic reaction times decrease with increased illumination;[15] and the reduced contrast results in a reduction of SVA and eye movement control.[16]

DVA shows a positive relationship with presentation time of the target.[4]

VA change is independent of the direction of movement of the target; and the horizontal, vertical and circular directions show a high intercorrelation.[12,14] If the individual's DVA is velocity susceptible in one plane of pursuit, it is likely to be velocity susceptible in the other planes of pursuit.[12]

There is a steady decline in visual acuity with age, which is more pronounced with target movement.[3] Males generally perform better than females on DVA tests, although the reasons have not been adequately investigated.[3,17,18]

Barmack[10] lists three factors necessary for good DVA: 1) foveal acuity, 2) oculomotor control, and 3) parafoveal acuity. Adequate foveal acuity is demonstrated by SVA, which explains the high correlation of SVA and DVA at low angular velocities. Parafoveal acuity becomes a factor during position errors, yet when the image is moving across the retina, the acuity is reduced significantly below the static acuity of the same retinal position.[7,19] Most investigators agree that the major factor in DVA is the efficiency of the entire oculomotor system.[4,14] Brown found that he could correlate the measured DVA to position and velocity errors determined from eye movement recordings.[11] The movement of the image across the retina reduces the contrast gradient of the retinal image, which explains why increases in illumination improve DVA.[7]

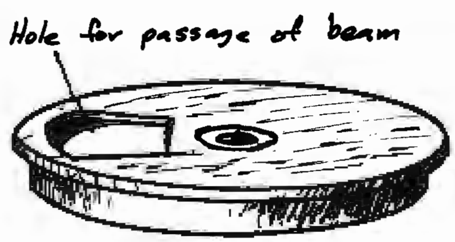
In a clinical setting, the SVA is used to indicate the minimum angular levels of visual discrimination. DVA not only demonstrates these levels of visual discrimination, but also gives the practitioner insight into the effectiveness of the entire oculomotor system.[4]

INSTRUMENT DEVELOPMENT

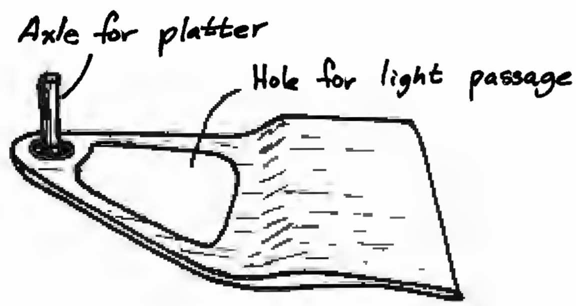
The dynamic visual acuity instrument was constructed from parts of a salvaged record turntable, and other miscellaneous components easily acquired from a hobby shop and an electronics parts store. This instrument, which can be placed in front of any typical slide projector, features mirrors placed on the turntable which rotates at various controllable speeds and a speedometer which directly indicates the rate at which the turntable rotates.

The instrument was designed to produce two types of motion of the targets: 1) linear motion in which the target moved horizontally across the screen, and 2) a circular pattern like that of a rotator. Mirrors for both methods of target movement were mounted on the same turntable. These mirrors were purchased from Edmund Scientific Company, and were 50mm by 80mm and 1mm thick.

The turntable was stripped of all but the platter and supporting framework including the axle and bearings. The circular projection method required that the projected light pass through the platter, consequently, the appropriate openings were made in the platter and frame:

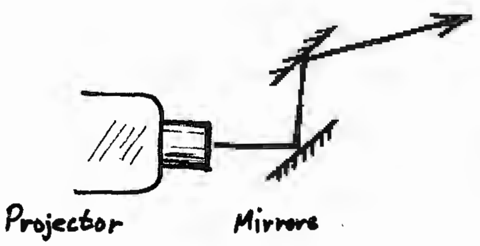


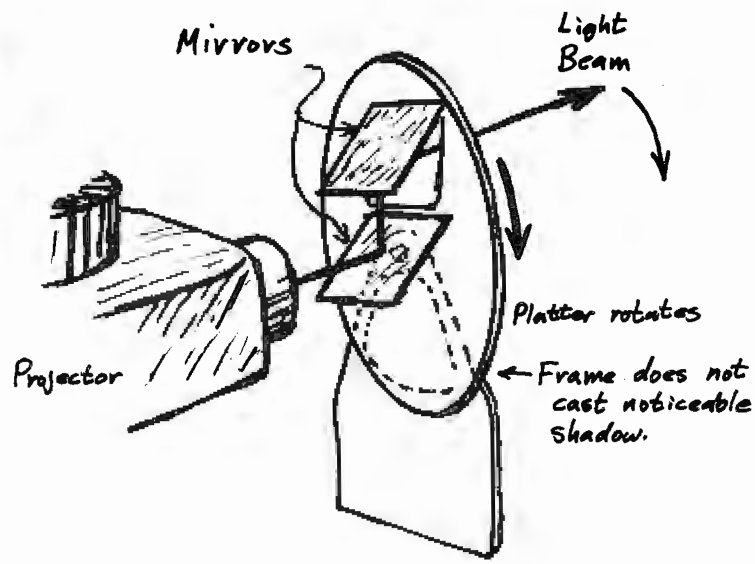
PLATTER



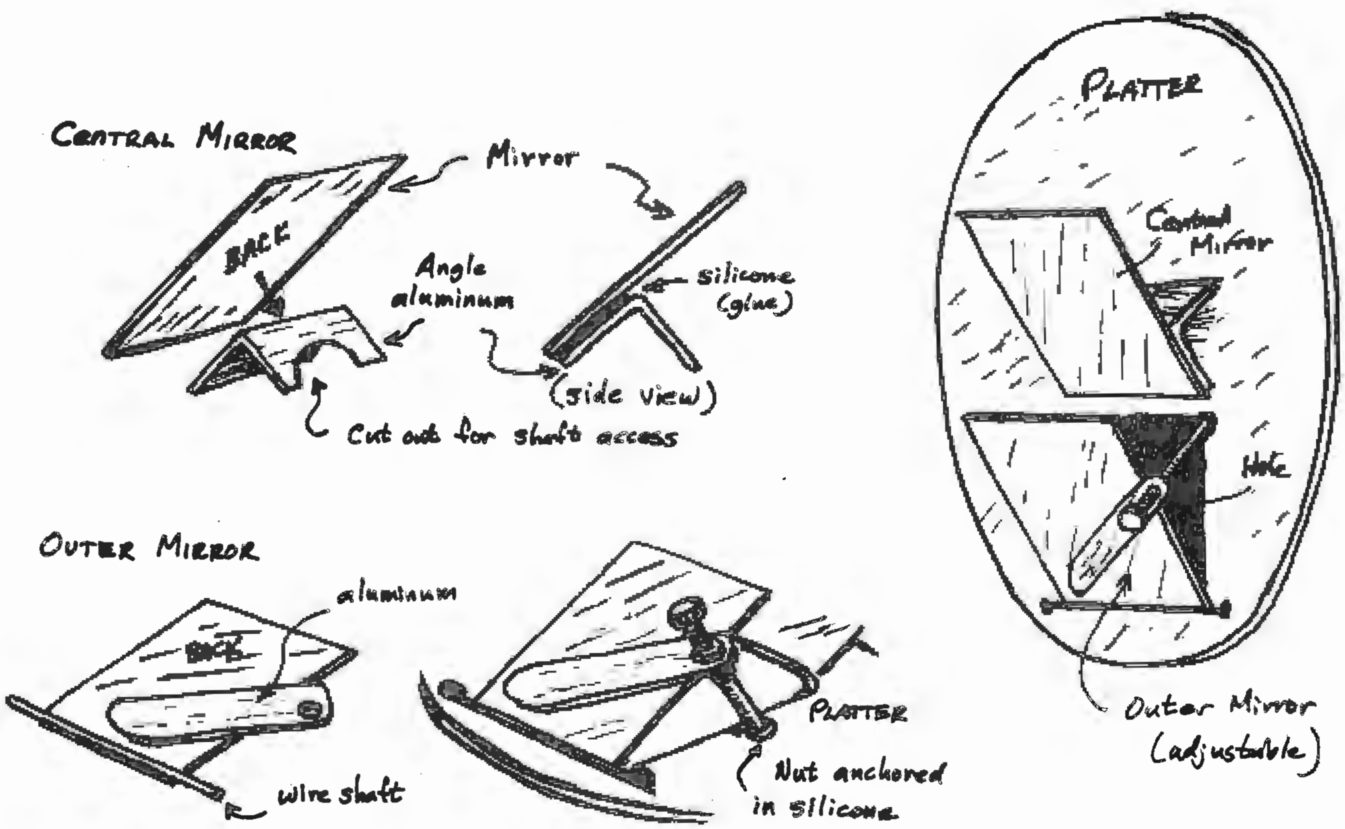
FRAME

For the circular motion, the mirrors were arranged as in a periscope, so that the light beam was deviated 90° by the first mirror, which was placed in the center of the platter, to the second mirror which deviated the light throught the hole in the platter and to the screen. This second mirror was arranged to deviate the beam less than 90° so that the beam did not travel to the screen parallel to the projector. Therefore, as the platter rotated in the frontal plane to the projector, the beam was deviated in a circular pattern to the screen.



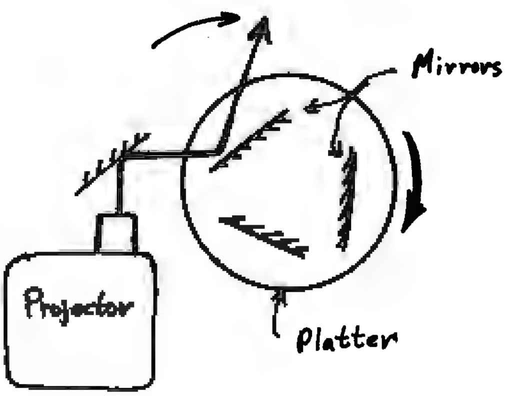


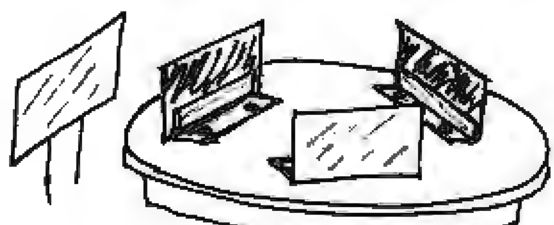
A one inch aluminum right angled stud and silicone sealant were used to mount the mirrors to the platter. The central mirror was stationary, and the outer mirror was adjusted to control the diameter of the circular pattern. For each turn of the platter, the target would complete one full circle with the diameter of that circle controlled by the adjustment of the mirror.



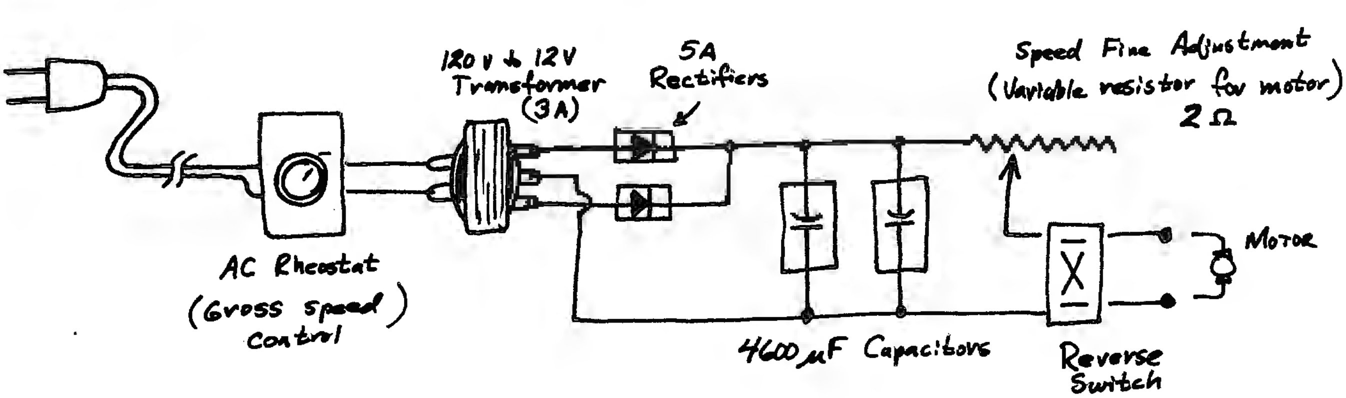
For the linear movement, one mirror was placed in front of the projector to deviate the light 90^{o} toward the platter which was rotating in a horizontal plane. Three mirrors were mounted on the platter to cause the beam of light to sweep across the screen in a "lighthouse" fashion. These mirrors were glued to the aluminum setup with two dabs of silicone adhesive (care must be taken not to warp the mirrors during the mounting process). The assembled unit was then mounted to the platter with small nuts and bolts.

For each turn of the platter in the linear mode the target would be presented three times. Therefore, as the speed of rotation was increased, the presentation time of each target pass and time interval between passes decreased.

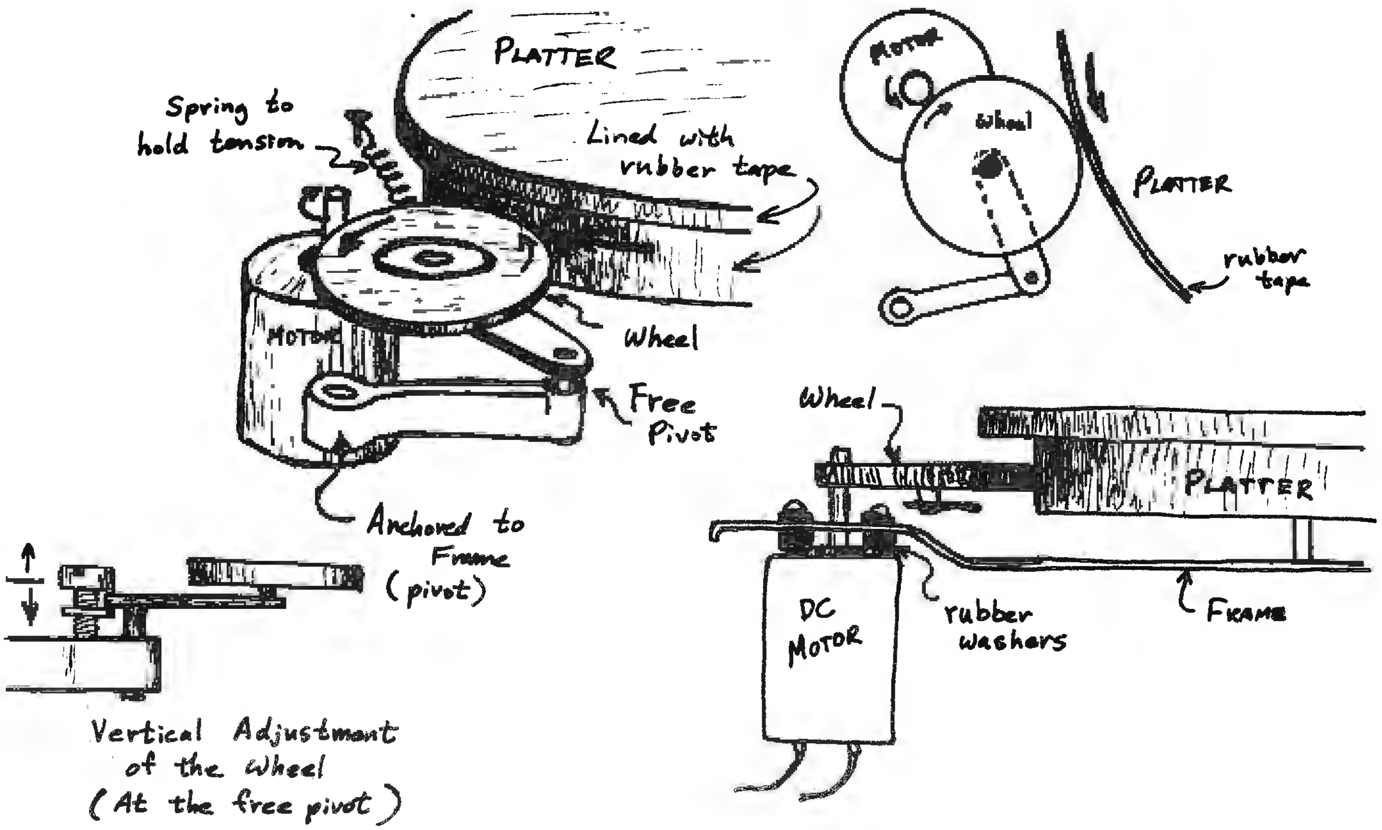




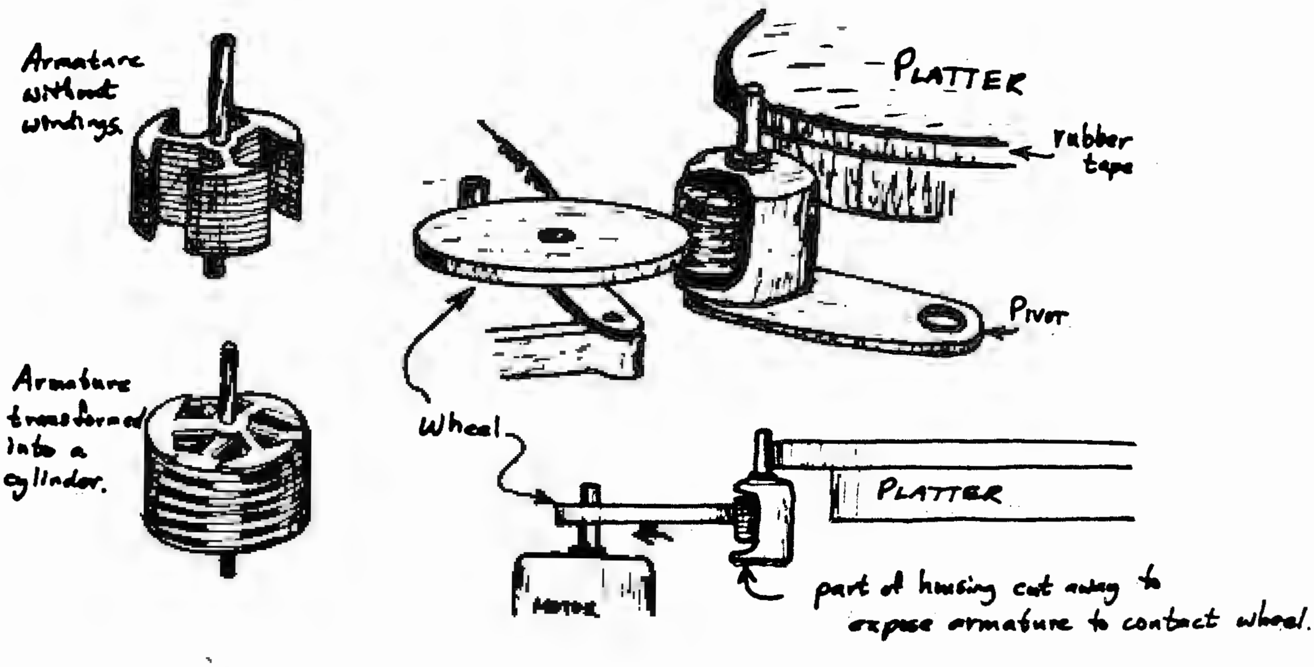
The motor to drive the system was purchased from a hobby shop. It was a 1/12 scale DC motor used in model race cars (RC controlled) and was mounted to the frame with rubber washers. The power supply was made with components from a retail electronics store:



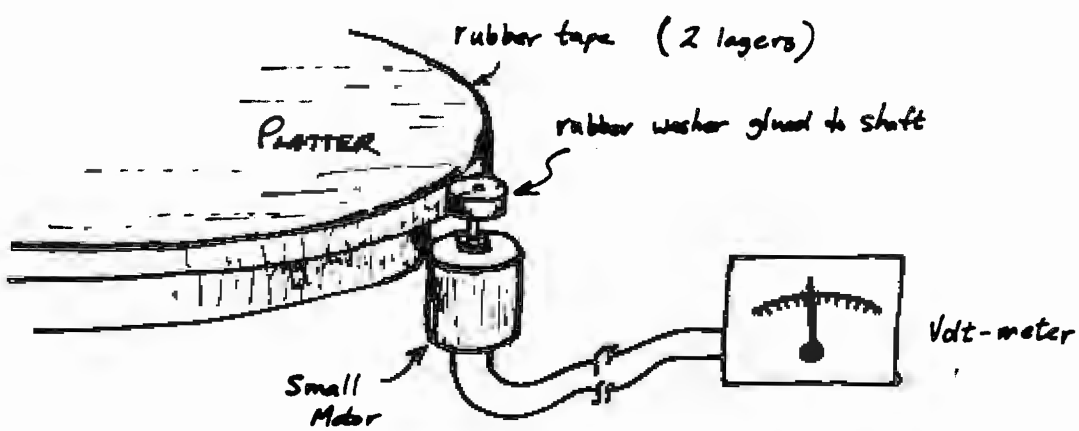
Since the record player was a direct-drive system, some of its drive-train could be used. The wheel which transferred the motion from the motor to the turntable featured a double-pivot sytem so that it was able to maintain contact with both the motor and table at all times. For use in the DVA instrument, this wheel had to be mounted outside of the platter to prevent it from interfering with the light beam.



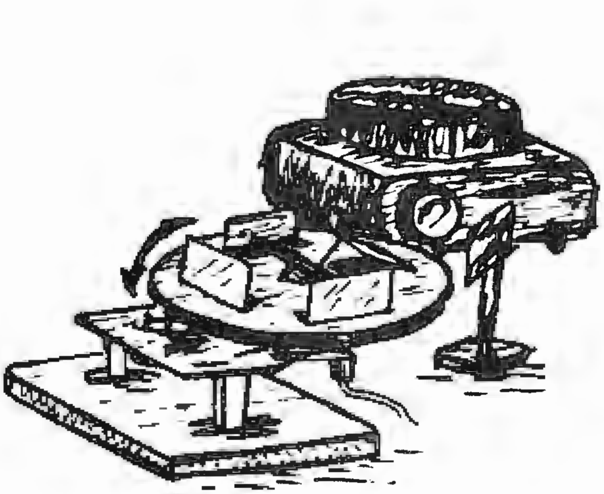
The motor speed was adequate for the circular motion but too rapid for the linear motion. Therefore, another component had to be installed to reduce the speed. This was accomplished by modifying a small electric motor such that the armature was extracted and the windings were removed. The framework for these windings was made in several layers, so that every other one could be turned a certain amount converting the armature into a cylinder. The field magnets were removed, and nearly half of the housing was cut away so that when the armature was replaced the exposed area allowed contact with the wheel. This unit was then installed so that the wheel, which was turned by the motor, contacted and rotated the modified armature, and the axle contacted and rotated the platter. This provided an approximate mechanical ratio of 7:1.

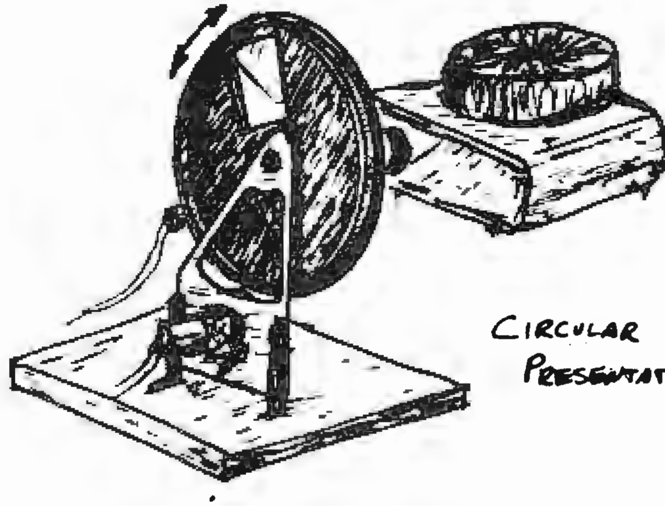


The speed of the rotation was controlled by a rheostat, and the speed of rotation was measured directly at the turntable. A small electric motor was placed so that it would be turned by the rotating platter. In this way it functioned as a small generator which put out a voltage proportional to its speed of rotation. This voltage was measured with a multimeter and converted to angular velocity, which meant that speed could be measured independently of all other electronic conponents.



The device was then mounted on a pivot stand so that it could be placed in front of the projector in either a horizontal or vertical position.





The revolutions per minute (rpm's) of the turntable were counted at several different meter settings. The rpm's were converted into the angular velocity* of the target with respect to the patient and those values were plotted on a graph opposite the values of the meter readings.

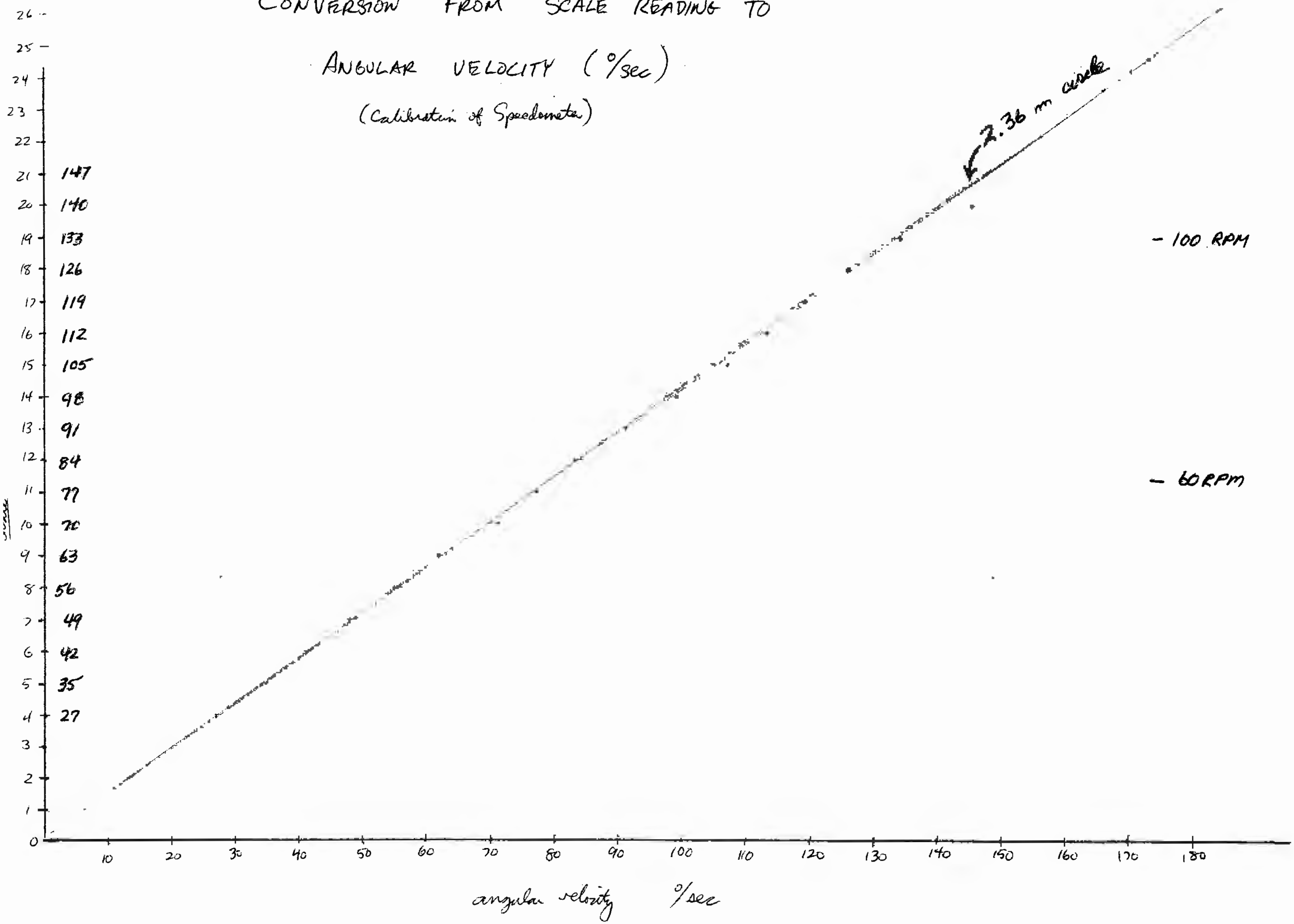
Since the subject was seated next to the projector, the angular velocity of the target during the linear presentation was equal to the angular velocity of the platter, i.e. 360^{o} per revolution.** For the circular presentation, however, the circumference of the circular pattern had to be determined. This was the distance that the target moved with each rotation, from which the target velocity was determined and converted into angular velocity depending upon the subject distance.

*See graph 1, p. 10.

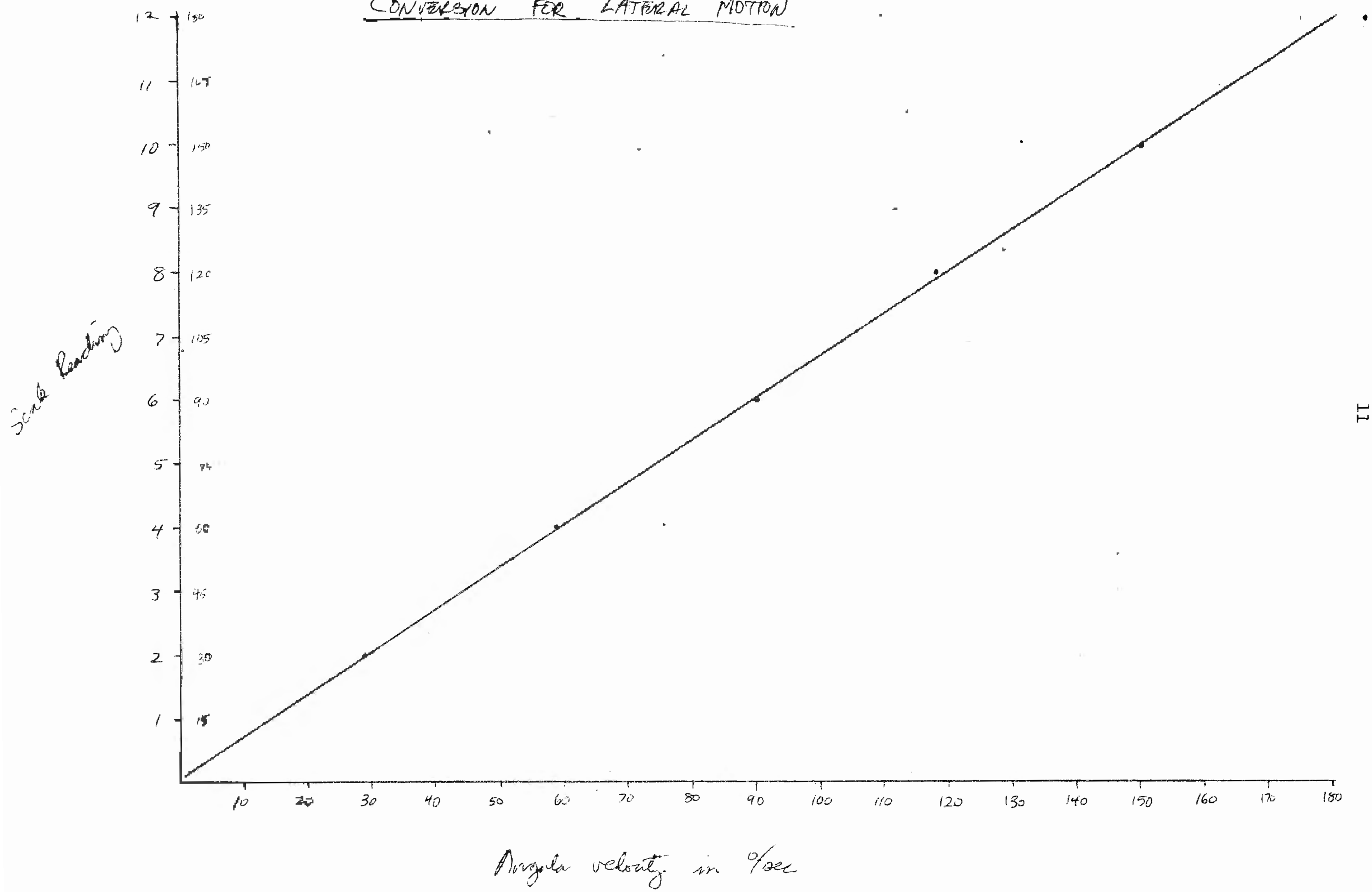
**See graph 2, p. 11.

CONVERSION FROM SCALE READING TO ANGULAR VELOCITY (°/sec)

(Calibration of Speedometer)



CONVERSION FOR LATERAL MOTION

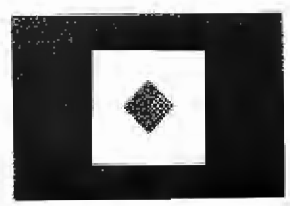


TARGET DESIGN

The targets were printed in negative form (white on black) and photographed on Kodalith film. These negatives were mounted and used as target slides so that the presented target was black on white. The visual acuity demands of the targets ranged from 20/15 to 20/400.

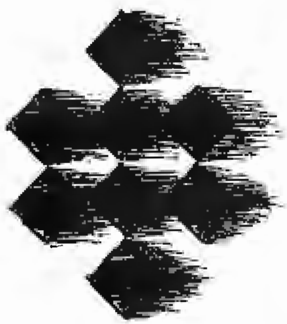
The letter targets consisted of a series of slides each containing three letters, which were in a 5X5 serif style format. The separation between the letters was 3/5X the letter width, while the white area surrounding the letter groups was 4.2X a letter width on each side, and 3X a letter width at both the top and bottom. The letters were matched so that the average readabilities of the letter groups were about the same, with the letters arranged from left to right according to increasing difficulty. The letter B was used as the standard since it is generally considered the most difficult letter to read.[20] All letters used have the following coefficients for static visual acuity:[20]

L: .70	Y: .80	E: .85
T: .74	F: .81	R: .85
V: .78	P: .81	S: .88
U: .79	D: .81	G: .89
C: .79	N: .84	H: .92
O: .80	Z: .84	B: 1.00



Fourteen different combinations of the letters were tested (each had an acuity demand of approximately 20/150) on twenty-one subjects to investigate the relative difficulties of the combinations under dynamic conditions.

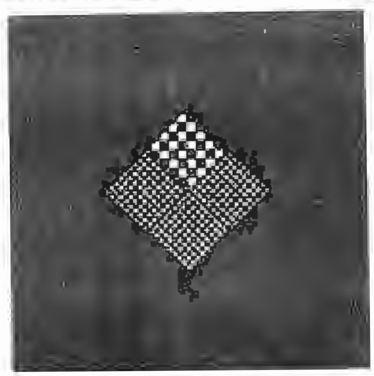
The checkerboard target was used as a check against the fact that the letters varied in difficulty and the fact that groups of letters are more easily memorized then checkerboards are memorized. The checks were alternated in a horizontal pattern so that inaccurate tracking during the horizontal presentation and the subsequent blurring on the retina would blur the checks evenly. The horizontal array blurs more homogeneously when inaccurately pursued during horizontal motion.



Diagonal Array

Horizontal Array

A photograph of a checkerboard target is shown below. These were printed in various sizes and then photographed on Kodalith film. The film negative was mounted as a slide and used to project the target. Thus, the square background surrounding the checkerboard was white, and the proportions remained the same as the target size varied.



SUBJECT SELECTION

Sixty persons volunteered as subjects from among the student body, faculty, and staff of Pacific University. Although a total of 60 subjects participated in one or more phases of the experiment, not all participated in each phase of testing. The subjects for each phase of testing were selected based upon age and sex so that each phase included subjects of both sexes who ranged in age from twenty to fifty years.

METHODS

The DVA instrument was placed in front of a 35mm slide projector, and its rotating mirrors deviated the light from the projector creating a moving target in either of the two modes: linear or circular. Each experimental run consisted of a series of slides of either letters or checkerboards ranging in acuity demand from 20/25 to 20/400. The slides were initially arranged in a random order which was maintained throughout each phase of the study.

Each subject was seated next to the projector facing a screen four meters away. The room lights were off to provide maximum target contrast. Each target was presented to the subject at an angular velocity faster than his discrimination threshold. As the velocity was gradually reduced the subject was instructed to call out what he perceived the target to be at the point in time when he was fairly certain of its content. If an incorrect response was made, the subject was quickly notified and he would continue to study the target until he was again fairly certain of its content. When a correct response was given, a voltage meter reading was taken and that data was recorded on that subject's personal data/graph form. The motion of the target was increased beyond threshold and the next target was introduced. This sequence was continued until the subject completed all of the targets in that run. The typical time required for a run of ten to twelve targets plus an additional practice pass of one slide was less than five minutes.

The data was collected in four phases:

Phase I: The target was moved in the circular pattern 2.5 meters in diameter at a distance of four meters from the subject, and head movements by the subject were not controlled. There were ten slides each of checkerboards and letters including ten different acuity demands ranging from 20/25 to 20/400. The 48 subjects in this phase made 26 runs with the letter targets and 38 runs with the checkerboard targets.

Phase II: 21 subjects participated in the assessment of the various letter combinations. The conditions were identical with those of phase I with the one exception that all the letter targets were of a 20/150 acuity demand.

Phase III: Thirteen runs on letter targets and ten runs on checkerboard targets were presented to fourteen subjects with no head movement restrictions. The target presentation was horizontal with the specific direction varying from left to right and right to left on different runs.

Phase IV: Nine subjects, four males and five females, participated in a repeatability analysis of individual performances. Checkerboard slides included six different acuity demands from 20/30 to 20/150 and three pairs of acuity demands ranging from 20/200 to 20/400. Letter slides included eight different acuity demands below 20/200 and three pairs of acuity demands above 20/200. Over a two week span each subject participated in a total of ten runs, two with letter targets and with no head movement restrictions, and four each with letter and checkerboard targets and with head movements restricted. Although the screen was not curved, the angular size and angular velocity of the targets with respect to the subject were constant since the subject was located immediately adjacent to the projector. A two factor analysis of variance was used to determine the test-retest repeatability .

RESULTS

The responses of each subject were plotted on a profile, Figure 1, pp. 17-18, shows a typical response pattern. The responses of all the subjects on each slide were averaged and plotted on the graphs in Figure 2, p. 19. Graphs (a)&(b) are of Phase I and graphs (c) and (d) are of Phase III, p. 20. Means and standard deviations are indicated in Tables I-IV, pp. 21-22.

The reliability results of the two factor analyses of variance of the subjects in Phase IV are listed below in Table V. N.S. means that the variability was not significant between the four runs, and where the variability was significant the probability (P) of the variance being a random event is shown. An asterisk (*) indicates when the subject showed significant improvement over the course of the four runs.

TABLE V

			LETTERS		CHECKERBOARDS	
SUBJECT	MALE	FEMALE	SMALLER	LARGER	SMALLER	LARGER
M.F.		x	$P < .01^*$	$P < .01^*$	$P < .01^*$	$P < .01^*$
R.P.	x		N.S.	N.S.	N.S.	N.S.
J.I.	x		N.S.	$P < .01^*$	$P < .01^*$	$P < .01^*$
R.S.	x		$P < .01^*$	N.S.	N.S.	N.S.
E.H.		x	$P < .01^*$	$P < .01^*$	N.S.	N.S.
L.G.		x	N.S.	N.S.	N.S.	$P < .01^*$
M.I.		x	$P < .05^*$	$P < .01^*$	N.S.	N.S.
K.H.	x		$P < .01^*$	$P < .01^*$	$P < .01^*$	$P < .01^*$
W.T.		x	$P < .01^*$	$P < .01^*$	N.S.	N.S.

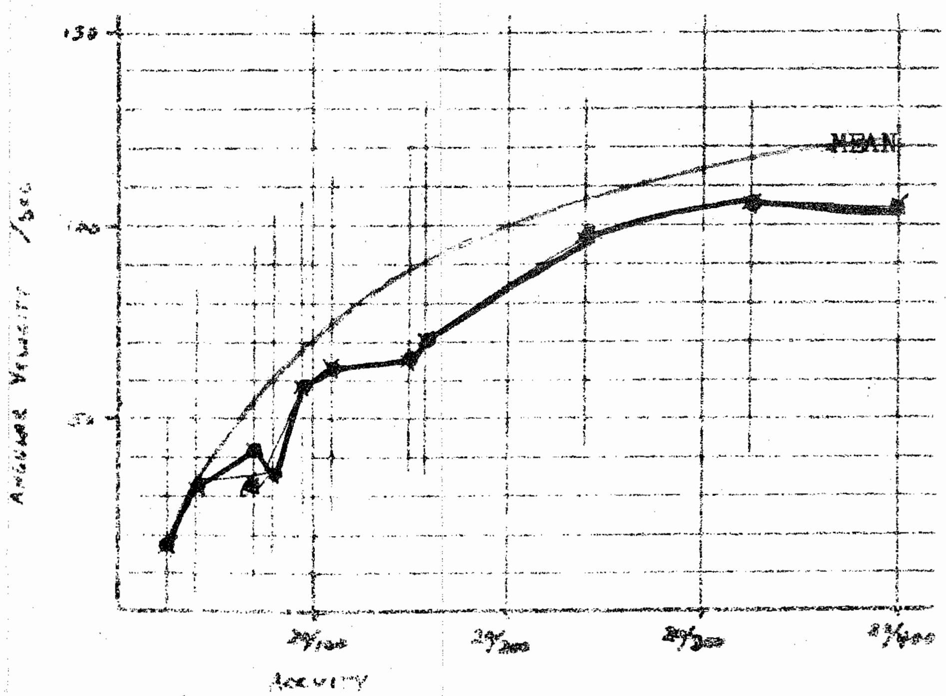
Smaller: acuities ranging from 20/25 to 20/225

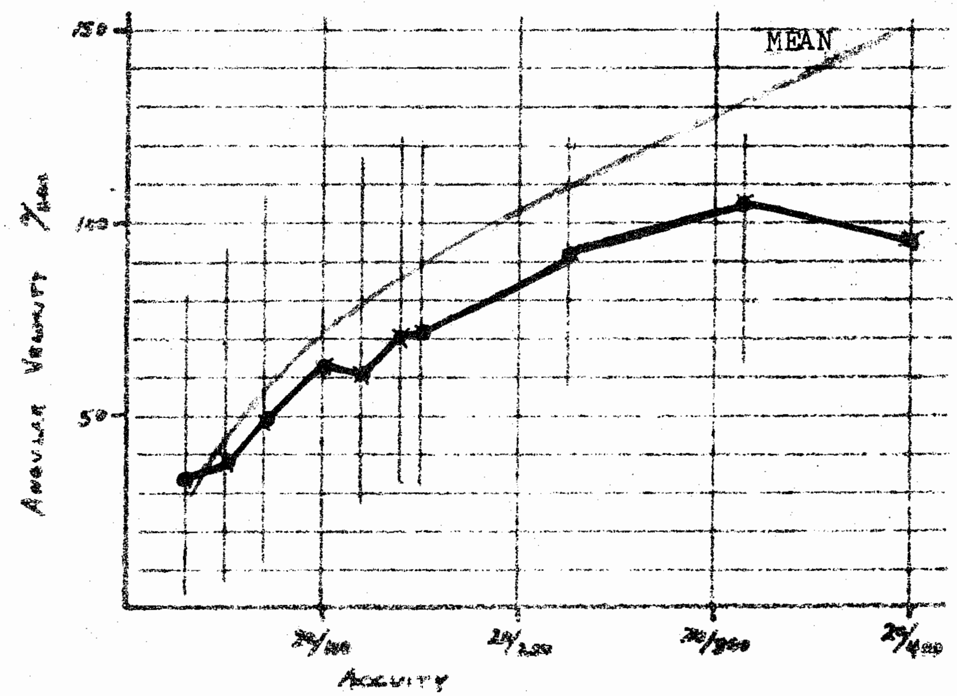
Larger: acuities above 20/200

COMMENTS PHASE I AA 3

LETTERS			CW Speed	CW °/sec	CCW Speed	CCW °/sec
1	20/95	OYS			8.3	59
2	20/325	LNG			14.9	105
3	20/40	VZE			4.5	32
4	20/400	VFG			14.6	102
5	20/150	UTB			9.0	63
6	20/70	VOH			6.0	42
7	20/25	CPN			2.6	18
8	20/110	CDE			9.0	63
9	20/80	UDZ			5.2	36
10	20/240	TFS			13.8	97
11	20/160	LZS			9.9	70
					54.2	

DIAMONDS			CW Speed	CW °/sec	CCW Speed	CCW °/sec
71	20/150	B			10.2	71
72	20/120	L			8.6	60
73	20/225	B			13.0	91
74	20/100	T			8.8	62
75	20/50	B			5.5	39
76	20/400	R			13.5	95
77	20/140	R			10.0	70
78	20/30	T			4.5	32
79	20/315	L			15.1	106
80	20/70	T			7.0	49
					67.5	





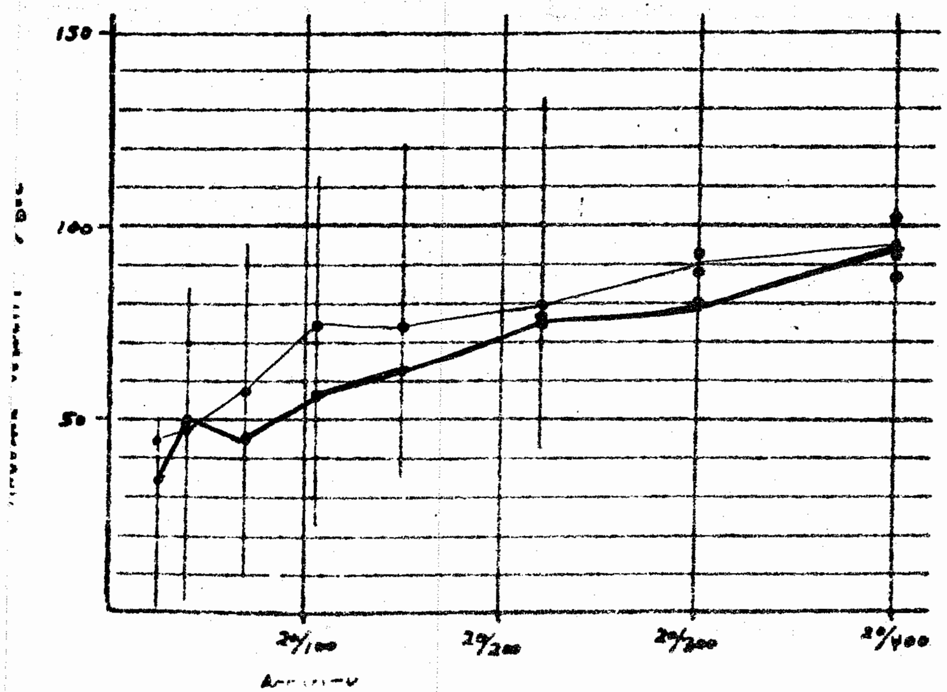
COMMENTS PHASE IV Run #2 AA

LETTERS

			CW Speed	CW °/sec	CCW With Head Movement Speed	CCW With Head Movement °/sec
2	20/105	VFG	3.8	57	4.9	74
3	20/400	OPH	5.8	87	6.1	92
4	20/40	VZE	3.3	50	3.2	48
5	20/300	LPG	5.3	80	6.2	93
6	20/150	UTB	4.1	62	4.9	74
7	20/70	VOH	3.0	45	3.9	58
8	20/25	CPN	2.3	34	3.0	45
9	20/220	UDZ	5.0	75	5.3	80
10	20/300	TNR	5.3	80	5.9	88
11	20/220	UFR	5.1	76	5.3	80
12	20/400	LZS	6.8	102	6.3	94
				68		75.1

DIAMONDS

			CW Speed	CW °/sec	CCW Speed	CCW °/sec
68	20/70	T	3.8	57		
69	20/320	L	8.2	123		
70	20/225	B	7.1	106		
71	20/150	B	5.6	84		
72	20/120	L	4.3	64		
73	20/370	T	8.9	134		
74	20/100	T	3.9	58		
75	20/50	B	3.0	45		
76	20/370	R	8.3	124		
77	20/225	R	6.1	92		
78	20/30	T	2.8	42		
79	20/320	B	6.9	104		
				86.1		



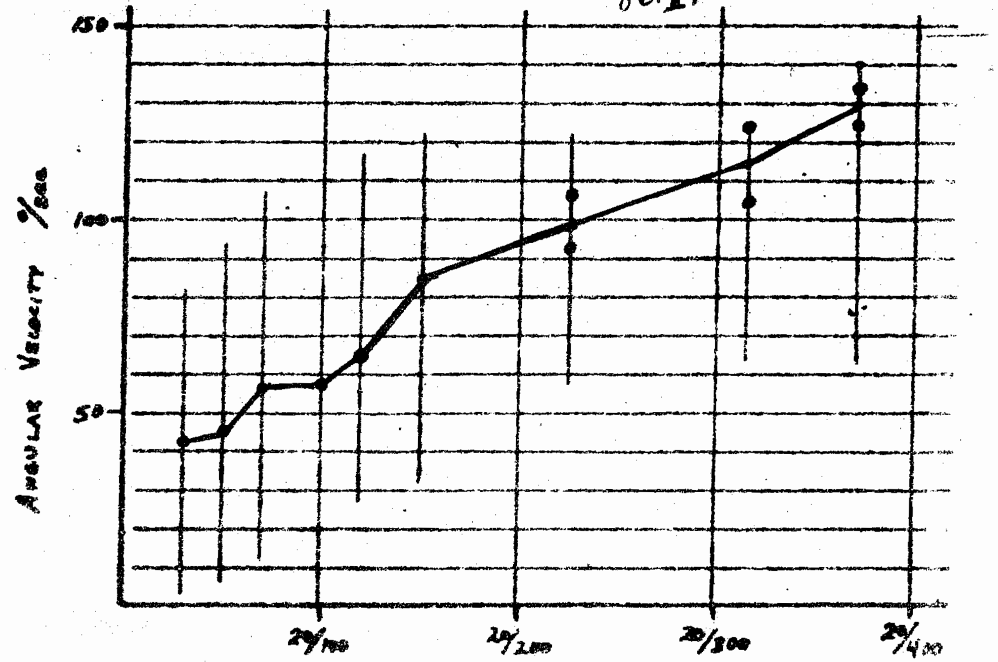
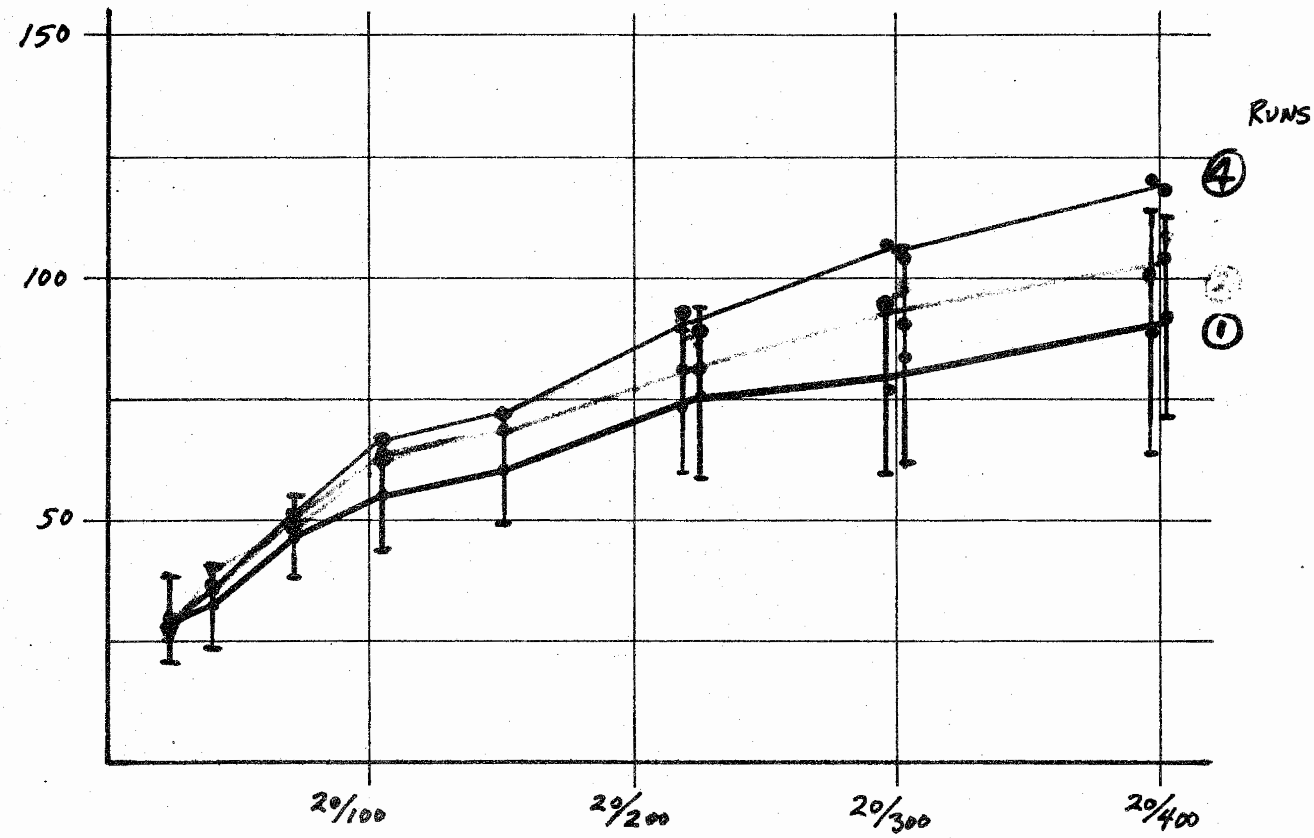
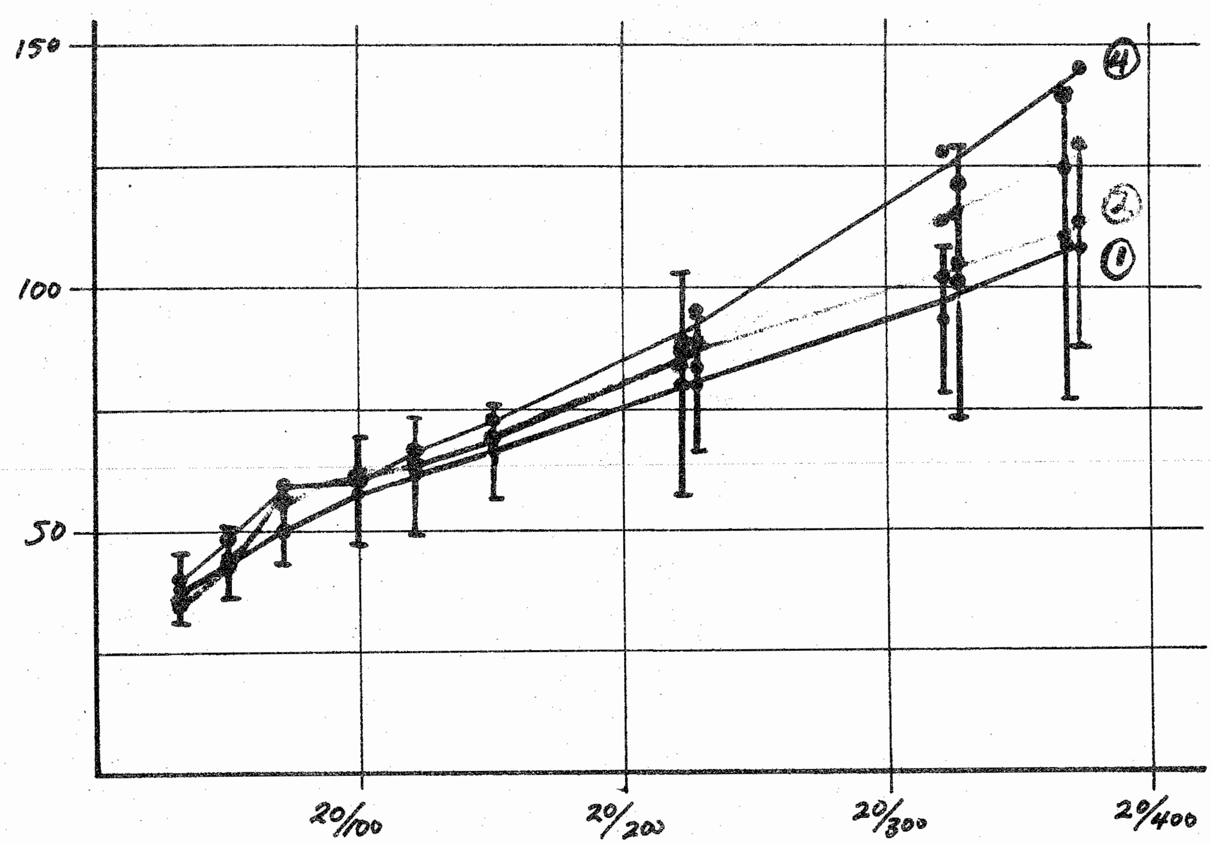
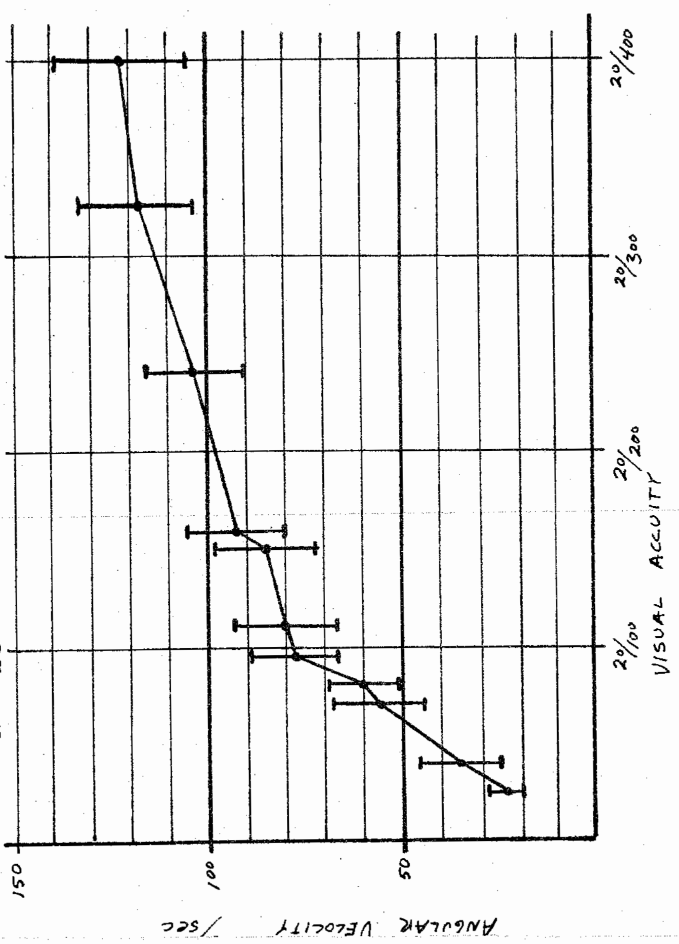


Figure 2

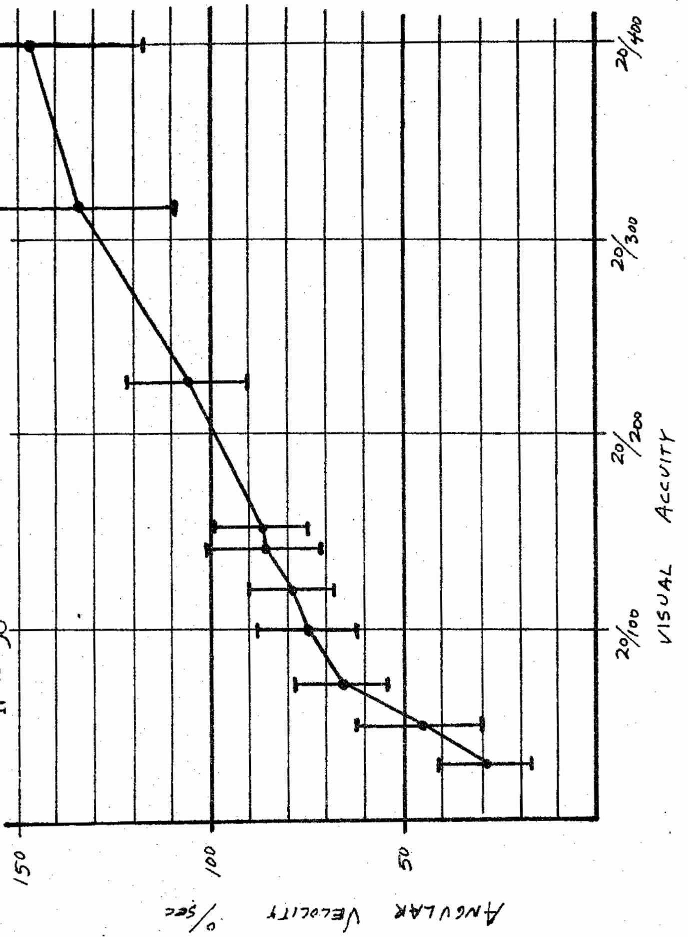
This shows the averages for each slide with each experimental run. Each run is shown in a different color. The S.D. is indicated for the first run.



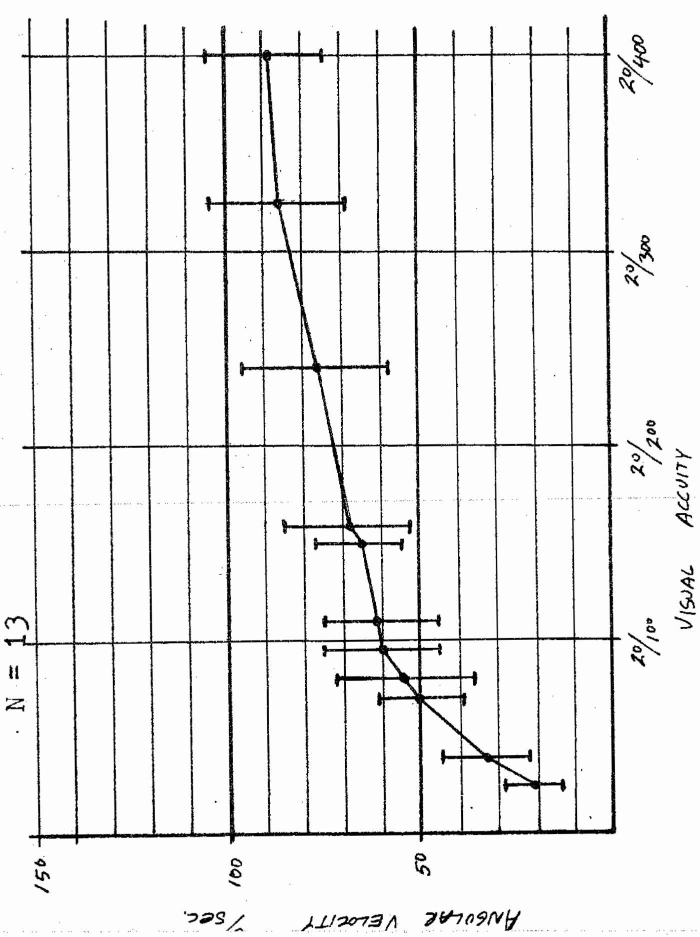




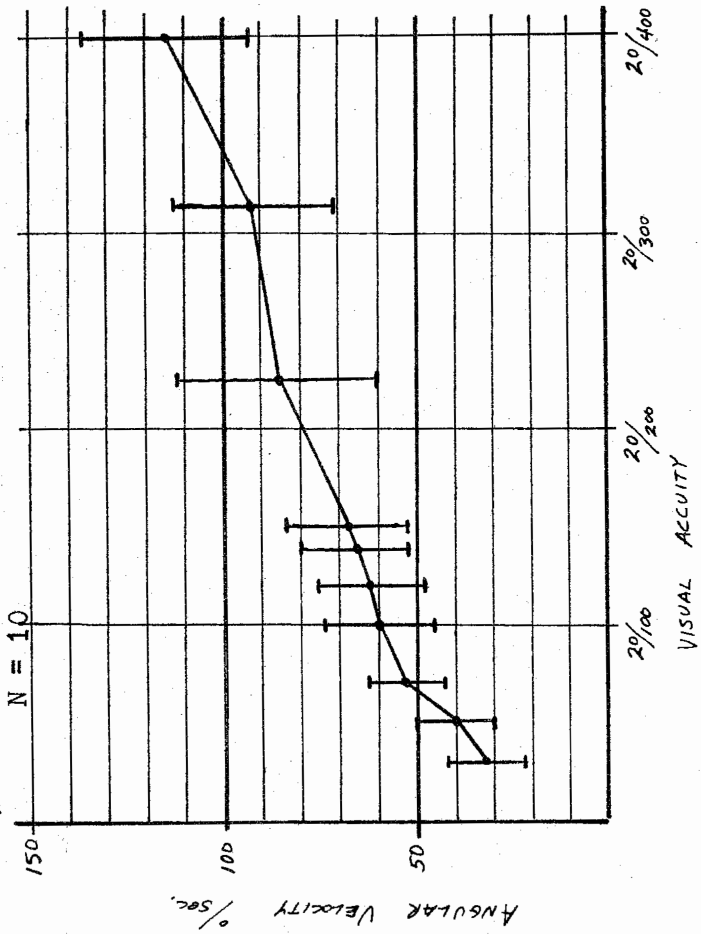
a) Circular Motion - Letters
N = 26



b) Circular Motion - Checkerboards
N = 38



c) Horizontal Movement - Letters
N = 13



d) Horizontal Movement - Checkerboards
N = 10

Table I

Means and S.D. of test population. CIRCULAR

LETTERS

accuity	$\bar{X}$	S.D.
20/25	24	4
20/40	36	10
20/70	56	12
20/80	60	9
20/95	78	11
20/110	80	13
20/150	85	13
20/160	93	13
20/240	103	13
20/325	118	15
20/400	122	17

CHECKERBOARDS

accuity	$\bar{X}$	S.D.
20/30	29	12
20/50	46	16
20/70	66	12
20/100	75	13
20/120	79	11
20/140	86	15
20/150	87	12
20/225	106	16
20/315	133	24
20/400	147	30

Table II

Means and S.D. LINEAR MOTION

LETTERS

accuity	$\bar{X}$	S.D.
20/25	21	7
20/40	33	11
20/70	50	11
20/80	54	18
20/95	60	15
20/110	61	15
20/150	66	12
20/160	69	17
20/240	77	19
20/325	86	17
20/400	89	15

CHECKERBOARDS

accuity	$\bar{X}$	S.D.
20/30	32	10
20/50	40	10
20/70	53	10
20/100	60	14
20/120	62	14
20/140	66	14
20/150	68	16
20/225	86	26
20/315	92	21
20/400	115	22

Table III

Means and S.D. of the reliability sample for the four runs.

LETTERS

	1st run		2nd run		3rd run		4th run	
accuity	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
20/25	29	9	30	3	26	14	28	7
20/40	32	8	35	8	40	8	36	7
20/70	46	9	51	8	48	9	51	8
20/105	55	12	64	14	63	11	66	12
20/150	60	11	68	12	72	17	72	9
20/220	76	18	81	18	85	24	89	23
	74	15	81	12	91	22	93	20
20/300	84	22	90	19	98	23	104	25
	77	18	95	21	94	21	107	26
20/400	88	25	101	30	100	32	120	26
	92	21	104	20	108	27	118	29

Table IV

Means and S.D. of the reliability sample for the four runs.

CHECKERBOARDS accuity	1st run $\bar{X}$	1st run S.D.	2nd run $\bar{X}$	2nd run S.D.	3rd run $\bar{X}$	3rd run S.D.	4th run $\bar{X}$	4th run S.D.
20/30	38	7	34	8	35	7	40	10
20/50	44	7	43	5	44	7	48	5
20/70	50	7	59	18	56	5	59	8
20/100	58	11	61	12	62	9	60	10
20/120	61	12	62	10	63	5	66	8
20/150	66	10	69	14	69	7	73	7
20/225	80	14	83	18	89	17	95	25
	80	23	89	24	84	8	87	24
20/320	93	15	102	23	114	17	128	26
	101	29	105	30	115	14	121	22
20/370	108	21	114	23	130	19	145	27
	109	32	110	29	124	20	139	23

With the letter targets, six of the nine subjects showed significant variability between the runs, five of the six subjects improved with each run. With the checkerboard targets three of the nine subjects showed significant variability on the smaller targets and four of the nine subjects showed significant variability on the larger letters: all seven subjects who showed significant variability also showed improvement. The average responses to each of the slides of the nine subjects for each run is shown in Table VI. The subjects showed a much greater rate of improvement on the larger letters compared to the smaller letters.

Because a large portion of the subjects showed significant improvement, further analysis was performed to determine whether the individual subject's performances with respect to the group were consistent throughout the runs. Each subject's responses to all of the slides during each run were averaged and are shown below in Table VI. The parenthesis ( ) indicate the rankings of the subjects on any particular run.

Subject	Letters 1	Letters 2	Letters 3	Letters 4	Checkerboards 1	Checkerboards 2	Checkerboards 3	Checkerboards 4
M.F.	71 (5)	91 (1)	94 (2)	103 (1)	75 (5)	89 (2)	84(4)	108 (1)
R.P.	80 (1)	80 (3)	75 (5)	83 (4)	83 (3)	82 (5)	78 (6)	85 (6)
J.I.	77 (2)	75 (5)	88 (3)	85 (3)	77 (4)	78 (6)	88 (3)	91 (4)
R.S.	57 (7)	60 (8)	62 (7)	69 (7)	71 (8)	67 (8)	71 (8)	
E.H.	72 (4)	82 (2)	95 (1)	96 (2)	86 (1)	87 (3)	89 (1)	95 (3)
L.G.	73 (3)	79 (4)	77 (4)	79 (5)	84 (2)	92 (1)	83 (5)	91 (5)
M.I.	59 (6)	66 (7)	58 (8)	59 (8)	71 (7)	69 (7)	73 (7)	72 (7)
K.H.	55 (8)	68 (6)	70 (6)	74 (6)	73 (6)	86 (4)	89 (2)	99 (2)
W.T.	40 (9)	50 (9)	50 (9)	57 (9)				

	Letters 1 to 2	Letters 2 to 3	Letters 3 to 4	Checkerboards 1 to 2	Checkerboards 2 to 3	Checkerboards 3 to 4
r	.86	.90	.97	.66	.75	.84
r_s	.67	.90	.97	.69	.55	.83

Letters: From 1 to 4: $r=.74$ $r_s=.65$ Checkerboards: From 1 to 4: $r=.33$ $r_s=.64$

r: correlation coefficient; r_s: Spearman ranking coefficient

Two methods of data analysis were employed. The correlation coefficient (r) was determined between the individual runs using the mean values of the subjects; and the Spearman rank coefficient (r_s) was a non-parametric test comparing the individual's rankings between the runs. The results are shown below in Table VII.

TABLE VII

Runs Compared	Letters				Checkerboards			
	1&2	2&3	3&4	1&4	1&2	2&3	3&4	1&4
r	.86	.90	.97	.74	.66	.75	.84	.33
r_s	.67	.90	.97	.65	.69	.55	.83	.64

A correlation coefficient of .69 would be considered to be significant at the .05 level of confidence.

The mean responses of the subjects in Phase IV were also used to compare the runs when head movement was allowed to those when head movement was restricted. The responses were found to be better with head movement allowed, significant at the .1 level of confidence.

Eleven subjects who participated in Phase I also were involved in either Phase III or Phase IV. These subjects' average responses, which occurred days apart, were used to compare circular motion to linear motion. The data is included in Table VIII below:

Subject	Circular (letters)	Linear (Letters)	(Checks)
J.I.	74.7	68.8	68.9
M.F.	81.5	67.7	69.1
J.N.	72	52.4	56.7
J.K.	70	42.4	49.4
R.S.	74.5	53.2	64.7
B.R.	93.5	63.5	66.0
R.P.	74.5	72.7	76.7
L.G.	80.4	70.2	75.1
M.I.	76.6	54.1	64.1
M.H.	86.4	58.7	65.3
D.V.	69.5	63.1	65.6

Between the letters with circular and linear motions: r=.32, and r_s=.36. Between the letters and checks on the linear phase: r=.93, and r_s=.98.

The groups of letters tested in Phase II are shown in Table IX below with the means and standard deviations of the angular velocities at which these letters were first recognized. Also shown are the visual acuity coefficients of the most difficult letter of the combination and the average of the coefficients of the three letters.

Letters	$\bar{X}$	S.D.	VA coefficient		
LNG	94	5.8	ave. .81	.89	most difficult
TFS	92	8.3	.81	.88	
VFG	90	10.1	.83	.89	
LZS	90	9.5	.81	.88	
OYS	89	10.7	.83	.88	
TNR	88	7.3	.81	.85	
UFR	86	8.7	.82	.85	
UDZ	85	9.0	.81	.84	
CDE	85	9.1	.82	.85	
UTB	85	9.6	.84	1.00	
LPG	84	9.6	.81	.92	
OPH	84	10.1	.83	.89	
VOH	83	9.1	.83	.92	
CPN	81	10.3	.81	.84	

During Phase IV there were two slides at each of the three highest acuity demands. A comparison of the average differences in the responses between these slide pairs should provide insight into the reliability of each subject within an experimental run. The average differences were significantly higher between checkerboard slides than between letter slides (at the .1 level of confidence with the Student t-test) in spite of the differing readabilities of the different letter combinations. This data appears in Table X below.

TABLE X

SUBJECT		LETTERS	CHECKERBOARDS
M.F.		6.25	16.00
K.H.		6.75	14.5
R.P.		15.70	14.6
J.I.		8.75	9.95
L.G.		9.17	7.92
W.T.		7.33	7.00
E.H.		11.17	19.67
M.I.		7.75	13.75
R.S.		10.11	10.89
	Average:	9.16	12.68

DISCUSSION OF RESULTS

For this device to become a useful tool, care must be taken to insure reliability. Most of the subjects in Phase IV were exposed to at least ten runs within a two week period, which would probably result in more learning than in a clinical situation in which testing may be done once per week at the most. The analysis of variance showed that there was more learning with the letters, probably because the subjects learned to recognize some of the letter combinations. Any improvement on the checkerboard targets was primarily due to improved skills of the subject involved in resolving the moving targets under the testing conditions. Table VI indicated that most of the learning occurred with the letter targets.

Although more subjects showed a significant variability on the letters than on the checkerboard targets, the letters showed a higher correlation between runs. If the subjects are not overexposed to the testing to the extent that they recognize individual letter combinations, the letters should prove more reliable than the checkerboards because the presence of contour interaction between the letters requires the subject to hold accurate tracking longer than would be necessary for the recognition of position in a checkerboard target. Subjects often reported that they could make out the first and last letters quite some time before they could identify the middle letter. When subjects are presented the checkerboard targets they could respond correctly by chance 25% of the time and with a little luck they may just catch the target for a fraction of a second--long enough to pick one of the four corners. On the average, subjects responded at higher velocities to the checkerboards than to the letters, and the checkerboard in the top or bottom corner yielded higher velocity responses on the average than when located in the left or right corners.

A comparison of the two slides at each of the higher acuities may show some insight into the reliability. An analysis of the average differences of threshold velocities between the slide pairs showed a significantly greater difference with the checkerboard targets than with the letters (at the .1 level of confidence). This indicates that even with different readabilities of letters, responses were more consistant with letter targets than with the checkerboard targets. The repeatability of the findings from run to run on different days would involve other factors such as the time of day, frame of mind of the subject, his recent history, attention, etc.. Therefore, if there is close agreement between the two slides at each acuity level and yet a significant difference between the runs, it may be safe to assume that the findings are reliable and there is some reason for the change in performance. On the other hand, if there is a large spread between the acuity pairs, there is likely a reliability problem with either the patient or the procedure. For this reason, it would be valuable to take two samples at each of the acuity demands. For example, take twelve samplings of two slides at six different acuity demands: 20/25, 20/50, 20/100, 20/150, and 20/200.

To get an accurate evaluation of the subject's DVA it would be important to restrict the exposure of the subject to the testing procedure. Otherwise, the improvement between tests may be credited to a training procedure when in fact the improvement may only be a response to the testing procedures. There was good agreement between the last three runs on the smaller targets (below 20/200 acuity demand), while the improvement on the larger targets showed no indication of leveling off. Therefore, it may be realistic on the smaller targets to expose the patient to the testing procedure until his performance asymptotes. For this procedure, however, the checkerboard targets should be used or the letter combinations should be varied to prevent memorization. If this device were to be used with a training procedure, it would be necessary to show transference to the real environment, and the testing procedure would have to be sufficiently different from the training procedure.

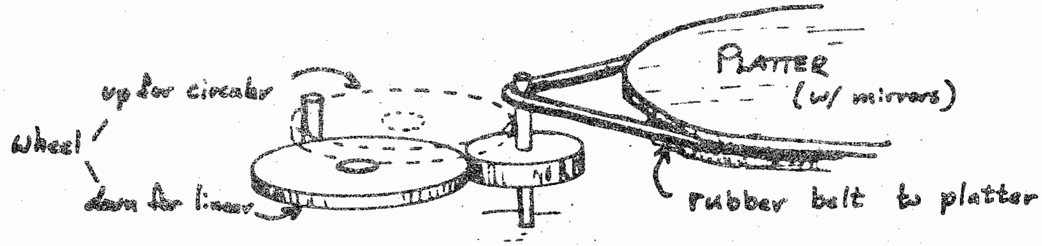
The analysis of the readability of the different letter combinations showed that there were differences, although they were not predictable by the static differences listed in Borish. For example, LNG and LPG look very similar and have equal average static difficulties, yet under the dynamic conditions of the circular presentation LNG was the easiest of the letter combinations and LPG was one of the more difficult. This difference was significant at the .01 level of confidence. The differences in dynamic legibility are probably due to differences in contour interactions which affect mostly the middle of the three letters in each group.

Each procedure (circular and linear) has its own advantages and disadvantages. The linear presentation may be the more realistic one in that more objects in the real world move in a linear rather than a circular fashion. However, the circular motion provides a continuous presentation, and that, combined with a tachistoscope, would provide equal time exposures for the different velocities. On the other hand, the linear motion results in shorter exposures as the velocity is increased which reduces the available time to perform the saccades while locating the target. The circular motion can be presented in a restricted area, while the linear motion needs a somewhat longer horizontal surface to provide sufficient time for the subject to lock onto the target especially at higher velocities. With the circular motion, the larger letters appeared to move in a smaller circle than the smaller letters, and there was more visceral discomfort reported with this motion. The two procedures showed about the same profiles of the means; the linear phase had generally lower averages, probably because the presentation of the targets was discontinuous. Ludvigh and Miller[7] reported a good correlation between the circular and linear presentations. Our procedure did not show this, which may be due to the fact that the subjects were run through each procedure on different days. Consequently, no conclusions are drawn regarding this relationship from this study.

Suggested improvements of the instrument design include:

The mirrors used were 1mm thick and warped too easily when mounted onto the platter, thus producing an astigmatic distortion of the target. Mirrors 3mm thick are more easily acquired and should prevent this type of distortion.

There was some annoying vibration produced by the direct drive arrangement of this device that showed up both visually and audibly. It is recommended tha a belt driven arrangement be used which should dampen most of the vibration from the drive train. In addition, a heavier platter should also reduce vibration, but care must be taken that the platter is carefully balanced.



The salvaged record turntable proved to be a convenient source of many of the mechanical parts, although almost everything could be acquired from scratch.

CONCLUSION

DVA can become an important measurement for visual functioning, especially in vision therapy and sports vision programs. This device can be useful for testing as long as precautions are taken to prevent learning from becoming a confounding variable. The targets may be made more sensitive by including four or five letters in each slide. Targets smaller than 20/200 showed more reliability than those larger than 20/200. This device should have application in the training of pursuits because there is active involvement of the patients and they are generally interested. It can also be a good demonstrator to the patients or their parents of the patient's visual problems. Binocular targets can be added to assess dynamic binocularity. This device is easy to use and can provide a complete DVA profile within a few minutes. If time is restricted, one or two slides can indicate whether or not there is a severe problem with the patient's DVA.

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